Energy Performance of Buildings

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Published in:
International Conference on Integrated Sustainable Resources in Arid Regions

Publication date:
2007

Document Version
Publisher's PDF, also known as Version of record

Energy Performance of Buildings – The European Approach to Sustainability

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ABSTRACT

"Sustainable development" has been defined best by the Brundtland Commission as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Adequate and affordable energy supplies have been key to economic development and are central to improving social and economic well-being, and human welfare and raising living standards. Even if energy is essential for development, it is only a means to an end. The end is good health, high living standards, a sustainable economy and a clean environment.

The European Climate change programme (ECCP) was established in June 2000 to help identify the most environmentally cost-effective measures enabling the EU to meet its target under the Kyoto Protocol, namely an 8% reduction in greenhouse gas emissions from 1990 levels by 2012. Energy use in buildings accounts for almost half of all CO_2 emissions in the EU and the building sector was identified as providing the largest potential for CO_2 reduction by 2012 and it was also identified to play an even more important role beyond 2012, where the European Commission's proposal for a Sixth Environmental Action Programme foresees a cost-effective energy saving potential of between 22% and 40% of the energy consumption in the sector by the year 2020.

The paper presents the European approach to improve sustainability in the building sector, which has a very high potential for considerable reduction of energy consumption and green house gas emissions in the coming years. By approving the Energy Performance in Buildings Directive the European Union has taken a strong leadership role in promoting energy efficiency in buildings in Europe, and the Directive will be the most powerful instrument developed to date for the building sector in Europe.

One of the benefits of the directive is that it provides an integrated approach to different aspects of buildings energy use and that all aspects are expressed in simple energy performance indicators. The integrated approach allows flexibility regarding details, giving designers greater choice in meeting minimum standards. In order to achieve a certain degree of harmonisation of assessment of buildings for designers and users throughout the EU, a common methodology based on an integrated approach is established. Based on a case the integrated approach and the methodology are presented and it is discussed how it can be used to optimise building performance.

Keywords: Sustainable buildings, energy performance, energy legislation

1. INTRODUCTION

'Sustainable development' has been defined best by the Brundtland Commission as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs, [1]. Adequate and affordable energy supplies have been key to economic development and are central to improving social and economic well-being, and human welfare and raising living standards. Even if energy is essential for development, it is only a means to an end. The end is good health, high living standards, a sustainable economy and a clean environment.

Much of the current energy supply and use, are based on limited resources of fossil fuels and are environmentally unsustainable. Pollutants are produced, emitted or disposed of, often with severe health and environmental impacts. Combustion of fossil fuels is responsible for urban air pollution, regional acidification and the risk of human-induced climate change. The UN Framework Convention on Climate Change required the adoption of policies and measures to reduce and limit greenhouse gas emissions in order to stabilise their emissions by 2000 at the 1990 level.

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In its Green Paper "Towards a European Strategy for Energy Supply", [2] the Commission highlighted three main points:

- The European Union will become increasingly dependent on external energy sources; enlargement will reinforce this trend. Based on current forecasts, if measures are not taken, import dependence will reach 70% in 2030, compared to 50% today.
- At present, greenhouse gas emissions in the European Union are on the rise, making it difficult to respond to the challenge of climate change and to meet its commitments under the Kyoto Protocol. Moreover, the commitments made in the Kyoto Protocol must be regarded as a first step; climate change is a long-term battle involving the entire international community.
- The European Union has very limited scope to influence energy supply conditions. It is essentially on the demand side that the EU can intervene, mainly by promoting energy savings in buildings and in the transport sector.

The residential and tertiary sectors have been shown to be the largest overall end users, mainly for heating, lighting, appliances and equipment, see the next section. Numerous studies and practical experience show that there is a large potential for energy savings here, probably larger than in any other sector, [3].

Figure 1 shows the results of a comparison of thermal building regulations in the European Union. It showed that rather extreme differences exist in building regulations even after these have been made comparable by correcting for climatic differences using so-called "degree days". The comparison was made by using the model building regulation of Denmark and applying it to each EU Member State after climatic correction. The results illustrates that an European initiative to improve the energy performance of buildings by promoting improved thermal insulation regulations to a level already attained by some countries could result in substantial energy savings for the EU as a whole.

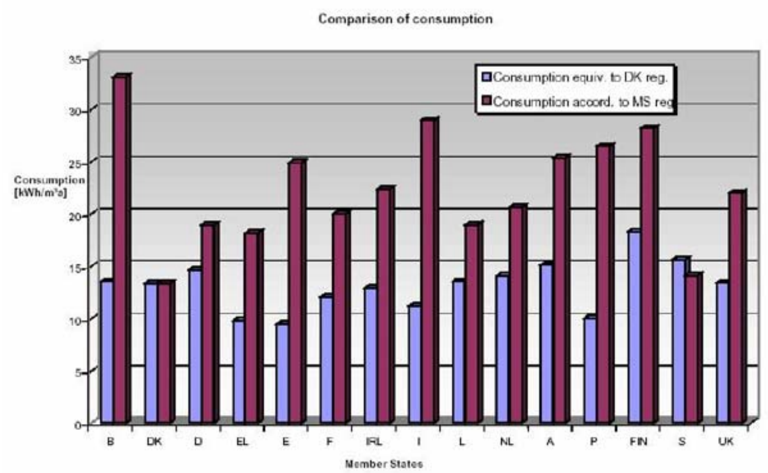

Figure 1: Energy consumption in EU Member States according to their existing national building regulations compared to the Danish model regulation adjusted for climatic differences, [4].

The European Union has taken a strong leadership role in promoting energy efficiency in buildings. While there are some individual countries that are playing an exemplary and leading role, most are following the lead of the Commission, the European Parliament and the Council of Ministers. This is among other things highlighted by the Directive on the Energy Performance of Buildings, which, once in full implementation phase, will be the most powerful instrument developed to date for the building sector in Europe

2. ENERGY USE IN EUROPE

The total final energy consumption in the EU in 1997 was about 930 Mtoe, [5]. A simplified breakdown of this demand shows the importance of buildings in this context. About 41 % is used in the residential and tertiary sectors, most of it for building-related energy services. Of this 2/3 is used in homes and 1/3 is used in commercial buildings. 31% of the total energy consumption is used for transport and 28% in the industry, [5].

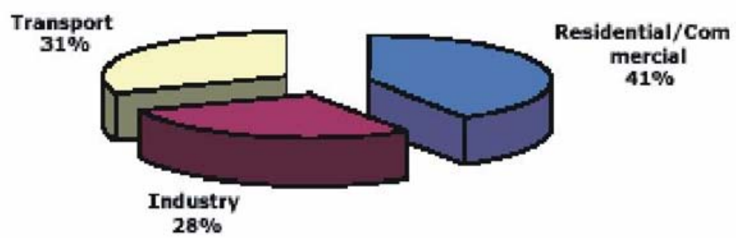

Figure 2: Distribution on sectors of total energy consumption in EU in 1997, [5]

Space heating is by far the largest energy end-use of households in EU Member States (57%), followed by water heating (25 %). Electrical appliances and lighting make up 11% of the sector´s total energy consumption, see Figure 3. For the tertiary sector, see Figure 4 the importance of space heating is somewhat lower (52 % of total consumption of the sector), while energy consumption for lighting and office equipment and "other" (which is mainly office equipment) are 14% and 16%, respectively.

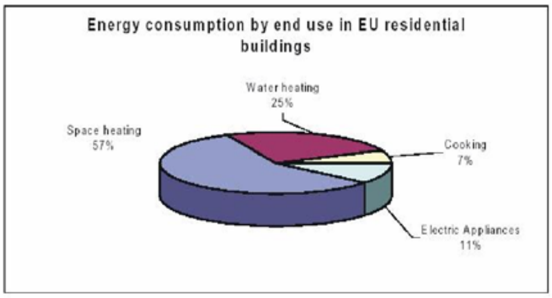

Figure 3: Energy consumption in the residential sector, [5]

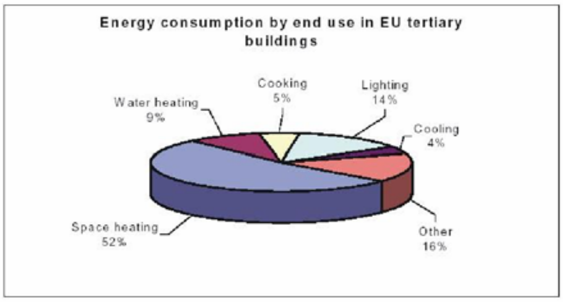

Figure 4: Energy consumption in the tertiary sector, [5]

3. ENERGY PERFORMANCE DIRECTIVE

All EU member states apply minimum standards, especially for new buildings, but considerable differences exist in the level of energy performance required in these standards, as it is seen in Figure 1, which indicate a large potential for improvement and a need for measures to realise this potential in the most cost-effective way. The Directive on the Energy Performance of Buildings, [6], is designed to promote the improvement of energy performance of buildings in member states.

One of the benefits of this directive is, that it provides an integrated approach to different aspects of buildings energy use, which until now only a few member states were doing, and that all aspects are expressed in simple energy performance indicators. The integrated approach allows flexibility regarding details, giving designers greater choice in meeting minimum standards. In order to achieve a certain degree of harmonisation of assessment of buildings for designers and users throughout the EU, a common methodology based on an integrated approach is established.

However, it should be recognised that the largest potential for energy saving is in the renovation of existing buildings and they should meet higher standards as regards energy performance when they are renovated. In order to address this issue, the most appropriate measure seems to be to introduce certification of buildings. In order to raise awareness, and at the same time remedy the major market imperfection that owners have no incentives to invest in buildings they rent out, the certification of public authority buildings or certain other buildings with high energy consumption, which are frequented by the public, should be displayed in the buildings, along with recommended and current indoor temperatures and relevant climatic factors.

In order to assist in developing a common methodology, standards bodies and others are involved in the implementation process. While all EU member states are free to implement on their own, there has been great emphasis on Communitywide collaboration.

3.1 Objective

Article 1 in the directive states the objective that is to promote the improvement of the energy performance of buildings within the Community, taking into account outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness. In the Directive requirements are given as regards:

(a) the general framework for a methodology of calculation of the integrated energy performance of buildings;
(b) the application of minimum requirements on the energy performance of new buildings;

(c) the application of minimum requirements on the energy performance of large existing buildings that are subject to major renovation;
(d) energy certification of buildings; and
(e) regular inspection of boilers and of air-conditioning systems in buildings and in addition an assessment of the heating installation in which the boilers are more than 15 years old.

3.2 Adoption of a methodology

Article 3 in the directive states, that member states shall apply a methodology, at national or regional level, of calculation of the energy performance of buildings on the basis of a general framework. The energy performance shall be expressed in a transparent manner and may include a CO2 emission indicator. The general framework for the calculation of energy performance of buildings is:

1. The methodology of calculation of energy performances of buildings shall include at least the following aspects:
   a. thermal characteristics of the building (shell and internal partitions, etc.). These characteristics may also include air-tightness;
   b. heating installation and hot water supply, including their insulation characteristics;
   c. air-conditioning installation;
   d. ventilation;
   e. built-in lighting installation (mainly the non-residential sector);
   f. position and orientation of buildings, including outdoor climate;
   g. passive solar systems and solar protection;
   h. natural ventilation; and
   i. indoor climatic conditions, including the designed indoor climate.

2. The positive influence of the following aspects shall, where relevant in this calculation, be taken into account:
   a. active solar systems and other heating and electricity systems based on renewable energy sources;
   b. electricity produced by CHP;
   c. district or block heating and cooling systems;
   d. natural lighting.

3. For the purpose of this calculation buildings should be adequately classified into categories such as:
   a. single-family houses of different types;
   b. apartment blocks;
   c. offices;
   d. education buildings;
   e. hospitals;
   f. hotels and restaurants;
   g. sports facilities;
   h. wholesale and retail trade services buildings;
   i. other types of energy-consuming buildings.

3.3 Setting of energy performance requirements

Article 4 requires member states to ensure that minimum energy performance requirements for buildings are set. It is allowed to differentiate between new and existing buildings and different building types. It is also required that member states review these requirements at regular interviews (not longer than five years) “to reflect the technical progress in the building sector.”

Article 5 states that for new buildings with a total useful floor area over 1000 m^2, the technical, environmental and economic feasibility of decentralised energy supply systems based on renewables, CHP, district or block heating or cooling and heat pumps shall be taken into account before construction.

Article 6 states that for existing buildings also with a total useful floor area over 1000 m^2 requirements can be set for either the entire renovated building or only for renovated systems or components.

3.4 Energy performance certificate

Article 7 states that energy performance certificates are required when buildings are constructed, sold or rented out and must be made available to the owner or by the owner to the prospective buyer or tenant. The validity of a certificate cannot exceed 10 years. The article further states: “Member States shall take measures to ensure that for buildings with a total useful floor area over 1 000 m2 occupied by public authorities and by institutions providing public services to a large number of persons and therefore frequently visited by these persons an energy certificate, not older than 10 years, is placed in a prominent place clearly visible to the public.” Article 7 also states that the range of recommended and current indoor temperatures and other relevant climatic factors may be clearly displayed as well, in order to ensure a balance between demands for energy performance and indoor environment. Figure 5 shows an example of a energy performance certificate from Denmark.

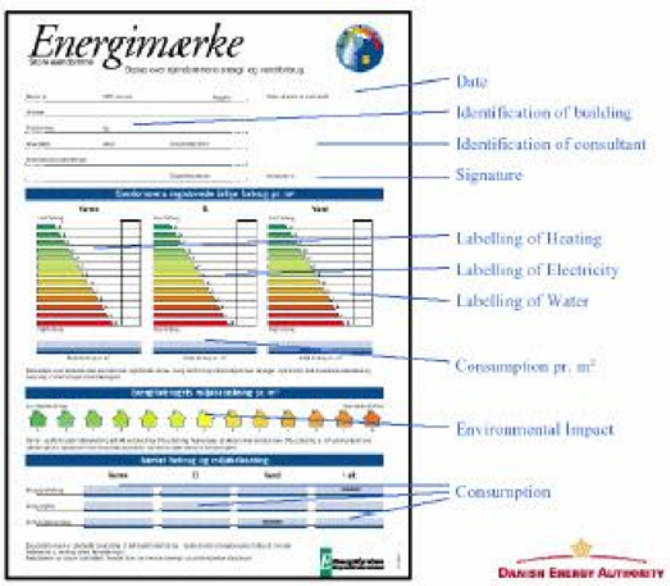

Figure 5: Danish Energy Performance Certificate for Buildings.

3.5 Inspection of boilers

Article 8 states that either the member state “lay down the necessary measures to establish a regular inspection of boilers fired by non-renewable liquid or solid fuel of an effective rated output of 20 kW to 100 kW” or “take steps to ensure the provision of advice to the users on the replacement of boilers, other modifications to the heating system and on alternative solutions which may include inspections to assess the efficiency and appropriate size of the boiler.” The impact of the second option has to be “broadly equivalent” to the first one.

3.6 Inspection of air-conditioning systems

Article 9 states that member states “shall lay down the necessary measures to establish a regular inspection of air-conditioning systems of an effective rated output of more than 12 kW.

3.7 Independent experts

Article 10 states that member states are required to ensure that “drafting of recommendations on the inspection of boilers and air-conditioning systems for the certification of buildings” are undertaken by independent qualified and/or accredited experts.

3.8 Final Remarks

The “European Directive on the Energy Performance of Buildings (2002/91/EEC) is the most significant measure that has been adopted by the EU to reduce greenhouse gas emissions from buildings.

4. IMPLEMENTATION OF EPD IN DENMARK

The energy situation in Denmark is in many ways the same as for other European countries, see figure 6. The main difference is that Denmark is an energy exporting country and has a relatively high share of renewable energy.

	DK	S	UK	D	EU	USA	Japan
Degree of Self- sufficiency (%)	137	61	106	39	52	72	16
Renewable Energy -Share of TPES (%)	13.1	26.7	1.4	3.8	6.0	4.5	3.7
Energy Intensity (TPES/US$) [MJ per 2000 US$]	5.3	8.6	6.3	7.7	8.4	9.2	4.4
Total Primary Energy Supply per Capita [GJ]	161	241	164	176	160	328	170
Total Final Energy Consumption per Capita [GJ]	119	167	113	125	113	226	116
CO_2 Emissions per Capita [tonnes], 2002	9.5	5.6	8.9	10.2	8.4	19.7	9.5

Figure 6: International comparison of the Danish energy situation, [7].

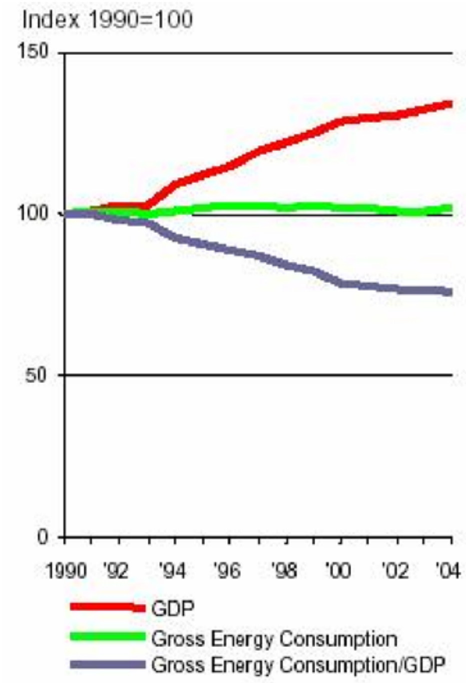

Figure 7: Development of GDP, gross energy consumption and energy intensity, [7].

The energy consumption has been stable due to a 20 per cent improvement in energy intensity between 1994 and 2005, see figure 7. The Kyoto commitment is to reduce GHG emissions by 21per cent in the first budget period 2008-2012, compared to 1990, which is far from reached at the moment.

As a basis for a new action plan on reduction of the energy consumption a number of investigations were performed. It was concluded that an economic reduction in the industry of 25% was possible, [9]. Another investigation concluded that a reduction of heating consumption in the residential sector of 45% before 2015 and up to 80% in the long term (before 2050) was possible, [10]. Table 1 summarises the socioeconomic potential for reduction of energy consumption until 2015 in Denmark.

Table 1: Socioeconomic energy saving potential, [11].

Type of Employment	Energy consumption 2003 (PJ)	Socioeconomic reduction potential until 2015 (%)
Room heating	**217,6**	**24**
Industrial process	**66,5**	**25**
Lighting	**24**	**24**
Cooling/freezing	**15,1**	**28**
Electric motors	**12,4**	**15**
Ventilation	**11,9**	**40**
Pumping	**8,4**	**35**
Other uses	**71,3**	**24**
Total	**427,2**	**24**

A new action plan on energy efficiency was approved by the government in December 2004 and released in early 2005. The energy conservation action plan is a forward-looking, market-based path, [12]. Basic principles for reorientation of the energy conservation drive are:

- Cost-efficiency.
- Promote competitiveness and welfare through low energy bills for companies and consumers.
- Focus on realisation of large, profitable savings potentials with low-cost measures
- A balanced approach in relation to the various sectors and energy applications.
- A market-based approach that promotes well-functioning and efficient markets for energy-efficient, profitable products and solutions.
- Prioritisation of international, and especially EU, initiatives.
- Promote the development of more efficient products that can help business development and exports, i.a. through research & development.

The new action plan calls for tightening the energy requirements in the building code by 25-30 % from 2006 and a further 25 % from 2010. The new action plan calls for a general target for reducing energy consumption in all sectors (not transport) of 1.7 per cent per year until 2013.

In June 2005, the Danish Parliament approved and published the new energy requirements for the building regulations of small houses and for the general building regulations. These fulfil requirements for articles 3, 4, 5 and 6 of the Energy Performance in Buildings Directive. The new requirements come into force January 1, 2006. The new requirements will reduce energy consumption by 25-30 % in new buildings.

A new law on Energy Savings in Buildings was also approved in June 2005. It will require energy labelling of all public buildings every five years, regular energy labelling of all large buildings (over 1000 sq. m. gross area) for trade and services as well as for apartment blocks. For building and apartments for sale or rent, the energy label is only valid 5 years. Energy labelling includes inspection, certification and advising. All new buildings have to be labelled to ensure fulfilment of the energy requirements in the building regulations.

The new requirements for energy consumption in new buildings set requirements for primary energy consumption for heating, cooling, domestic hot water, ventilation and lighting (not included for residential buildings). In the calculation of the primary energy consumption electric energy is weighted with a factor of 2.5 in relation to heating.

The primary energy consumption for residential buildings must not exceed:

$$(70 + \frac{2200}{A}) kWh / m^2 year$$

where A is the heated floor area of the building.

The primary energy consumption for other buildings must not exceed:

$$(95 + \frac{2200}{A}) kWh / m^2 year$$

In order to classify a building as a low energy building class 1 or 2, respectively, the energy consumption must not exceed:

Class 1: $(35 + \frac{1100}{A}) kWh / m^2 year$ Class 2: $(50 + \frac{1600}{A}) kWh / m^2 year$

Besides requirements on the energy consumption the building regulations also puts requirements on airtightness (1,5 l/s m^2 floor area at a pressure difference of 50Pa) and heat loss (6W/m^2 envelope, except windows and doors, at a temperature difference of 32 K). The latter means that the average U-value for the building envelope must not exceed 0,19 W/m^2K. Additional requirements consider heat recovery (min 65% efficiency) and fan power (SFP less than 2100 J/m^3).

5. IMPLICATION FOR THE BUILDING SECTOR AND FUTURE TREND

The new requirements for energy consumption in building in Denmark from January 2006, that implies a reduction of 25-30%, can be achieved by existing technology and typical structural solutions. It will require additional insulation thickness in building envelopes, more efficient ventilation, heating and lighting systems and a more optimal building design, but it will not require any radical changes in building construction.

However, by 2010 the requirements for energy consumption in new buildings will be tightened to class 2 low energy building requirements and by 2015-2020 to class 1 low energy building requirements. In order to fulfil such requirements typical U-values for building envelopes must be below U=0,1W/m^2K and for windows and glazed areas below U=0,8W/m^2K. Heat recovery efficiency should be about 75-85% and energy use for transport of air below 500 J/m^3 air. This will require development of new construction solutions, new types of building envelopes, new building materials as well as development of new integrated design approaches.

5.1 Low energy building concepts

Research into building energy efficiency over the last decade has focused on efficiency improvements of specific building elements like the building envelope, including its walls, roofs and fenestration components, and building equipment such as heating, ventilation, air handling, cooling equipment and lighting. Significant improvement have been achieved, and whilst most building elements still offer opportunities for efficiency improvements, the greatest future potential lie with technologies that actively respond to changing conditions and also promote the integration of responsive building elements and building services.

In this perspective Integrating Building Concepts are defined as solutions where responsive building elements together with building services are integrated into one system to reach an optimal environmental performance in terms of energy performance, resource consumption, ecological loadings and indoor environmental quality. Responsive Building

Elements are defined as building construction elements which are actively used for transfer of heat, light and air. This means that construction elements (like floors, walls, roofs, foundation etc.) are logically and rationally combined and integrated with building service functions such as heating, cooling, ventilation and energy storage. With the integration of responsive building elements and building services, building design completely changes from design of individual systems to integrated design of “whole building concepts, augmented by “intelligent” systems and equipment.

In order to address some of these issues an international research effort has been initiated. IEA-ECBCS Annex 44: “Integrating Environmentally Responsive Elements in Buildings” is a task-shared research project initiated by the IEA implementing agreement Energy Conservation in Buildings and Community Systems (ECBCS). The project runs for 4 years from 2005-2008 and involves about 25 research institutes, universities and private companies from 14 countries around the world, see www.civil.aau.dk/Annex44.

A whole building concept or integrated building concept includes all aspects of building construction (architecture, facades, structure, function, fire, acoustics, materials, energy use, indoor environmental quality, etc…) and consist of three parts:

- the architectural building concept,
- the structural building concept and
- the energy and environmental building concept

This corresponds to the three different main professions involved and each concept is developed in parallel by the three professions using their own set of methods and tools - but in an integrated design process leading to an integrated solution – the Integrated Building Concept.

Low energy building concepts can be classified to define/specify what is meant by the concept and to get an idea of what direction to take in the preliminary design phase. A general classification should not be too complicated and not with too many categories. An “Energy and Environmental Building Concept” can be classified according to the categories and parameters in Table 2.

Table 2. Categories and parameters for classification of Energy and Environmental Building Concepts

Category	**Parameter**
Climate	Cold, moderate, warm, hot-dry, hot humid, …
Context	Urban, suburban, rural
Building use	Office, school, residential, ...
Building type	High-rise, low-rise, row-houses, single houses, multifamily buildings, ...
Demand reduction strategies	Thermal insulation, air tightness, buffering, reduction of heat and contaminant loads, building form, zoning, demand control, efficient air distribution, solar shading, ..
Control strategy	Natural mechanism, adaptive/rigid, user control/automatic
Renewable energy technologies	Passive and active solar heating, wind, natural cooling, geothermal heat/cool, biomass, dayligthing, natural ventilation,..
Efficient energy conversion	CHP, HE gas boiler, heat pump, …

Examples of existing low energy building concepts are:

- The “Passive Building” concept which mainly focuses on super insulated and air tight envelopes combined with high efficiency heat recovery

- The “Solar Building” concept which mainly focuses on utilization of renewable energy technologies such as passive and active solar heating and solar cells
- The “Smart Building” concept which mainly focuses on advanced solutions for demand control and efficient use of fossil fuel technologies
- The “Adaptive Building” concept in which building elements actively respond to changing climate conditions and indoor environmental conditions as required by the occupants

Figure 8 shows an example of a low energy building project in the south western part of Sweden based on the “passive building concept”.

Figure 8. Measured performance of rowhouses, Lindås, Sweden.

It is seen that for this type of buildings (Class 1 in Denmark), where the energy use for heating, ventilation and domestic hot water is optimised, that the energy consumption for electric appliances in the household covers about half of the total consumption, which is a radical change from the typical situation, see figure 3.

The main challenge in the coming 5-10 years will be to implement the experience from this and similar demonstration buildings in the main stream construction work and further develop and optimize construction principles, envelope types and building components and systems to make these new technologies competitive in the market. Development of new low energy building concepts should search for an optimum combination of the existing concepts by using an integrated design strategy and the full range of technical solutions available.

5.2 Design strategy and technical solutions

In the development of a whole building concept or integrated building concept an integrated design approach is needed to enable the designer(s) to control the many parameters that must be considered and integrated, when creating more holistic building concepts. A design strategy based on the method of the “Kyoto Pyramid” is shown in Figure 9.

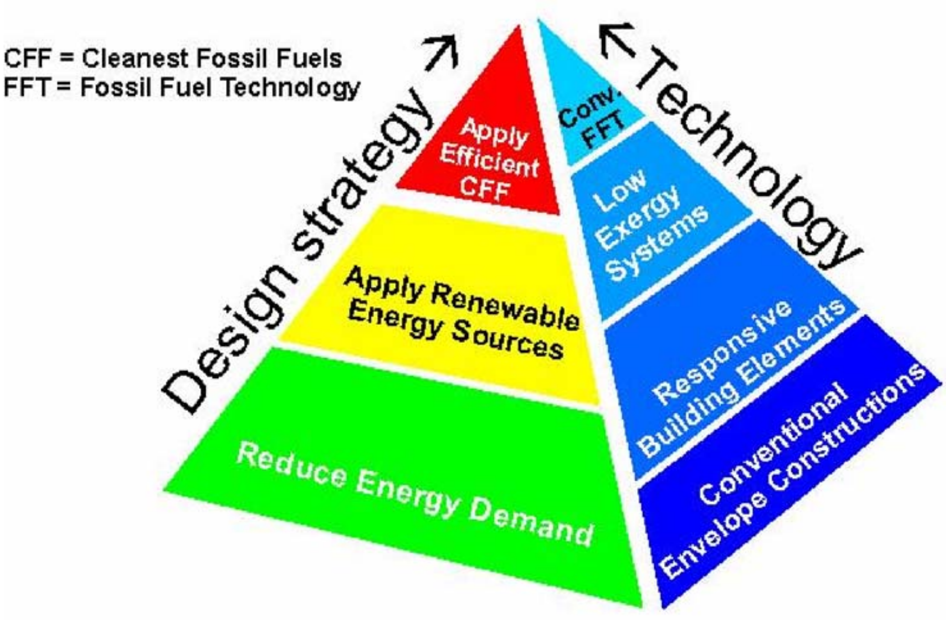

Figure 9: Illustration of design strategy and corresponding technologies developed in IEA-ECBCS Annex 44, Heiselberg 2006.

The Kyoto Pyramid (KP) is a strategy that has been developed for the design of low energy buildings in Norway, (Dokka and Rødsjø, 2005). It is based on the Trias Energetica method described by Lysen (1996). The left side of the pyramid shows the design strategies, and the right side of the pyramid shows the technical solutions that may be applied in each of the steps. In an integrated design strategy, the designer starts at the bottom of the pyramid, applying the strategies and technologies as follows:

Reduce Demand: Optimize building form and zoning, apply super insulated and air tight conventional envelope constructions, apply efficient heat recovery of ventilation air during heating season, apply energy efficient electric lighting and equipment, ensure low pressure drops in ventilation air paths, etc. Apply Responsive Building Elements if appropriate including advanced façades with optimum window orientation, exploitation of daylight, proper use of thermal mass, redistribution of heat within the building, dynamic insulation, etc.

Utilize renewable energy sources: Provide optimal use of passive solar heating, dayligthing, natural ventilation, night cooling, earth coupling. Apply solar collectors, solar cells, geothermal energy, ground water storage, biomass, etc. Optimise the use of renewable energy by application of low exergy systems.

Efficient use of fossil fuels: If any auxiliary energy is needed, use the least polluting fossil fuels in an efficient way, e.g. heat pumps, high-efficient gas fired boilers, gas fired CHP-units, etc. Provide intelligent control of system including demand control of heating, ventilation, lighting and equipment

The main benefit of the method is that it stresses the importance of reducing the energy load before adding systems for energy supply. This promotes robust solutions with the lowest possible environmental loadings.

5.3 Design methods and tools

In order to facilitate this design approach different types of design methods and tools that based on the selected design strategy makes it possible in a strategic way to select the most suitable technical solutions for the specific building and context. 5 main categories of design methods and tools can be identified: design process methods/tools, design strategy methods/tool, design support methods/tools, design evaluation methods/tools, and simulation tools.

The design process methods/tools gives guidelines on how to organise the work process itself, i.e. who should take care of what tasks at what stages of the development and design of an integrated building concept. It is necessary that the methods allow for consideration and solution of technical as well as aesthetical problems and that it focuses on the creative element in the process, in order to identify new opportunities and to work strategically in creating innovative solutions in a new building design.

The design strategy methods/tools are concerned with what issues should be considered at different stages of the development of a low energy building concept.

The design support methods/tools are typically used in the early stages of the design to get an idea of what approaches and technical solutions are the most promising for the given project and should be included in the developed low energy building concept.

The design evaluation methods and tools are typically used later in the design process to check the performance of a given design concept and technical solutions.

Simulation tools